Spatial distribution and morphometric measurements of circum-Caloris knobs on Mercury: Application of novel shadow measurements

SPATIAL DISTRIBUTION AND MORPHOMETRIC MEASUREMENTS OF CIRCUM-CALORIS KNOBS ON MERCURY: APPLICATION OF NOVEL SHADOW MEASUREMENTS. J. Wright[1], D. A. Rothery[1], M. R. Balme[1] and S. J. Conway[2], [1]School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK (jack.wright@open.ac.uk), [2]CNRS, Laboratoire de Planétologie et Géodynamique, Université de Nantes, France.

Introduction: The Caloris basin (1550 km diameter) is the largest, well-preserved impact feature on Mercury [1]. Its impact ejecta, excavated from the lower crust and uppermost mantle [2], provides an opportunity to investigate the interior materials of the planet.

Based on Mariner 10 data, which cover only the eastern third of the basin, 'hummocky plains', associated with Caloris, consisting of 'low, closely spaced to scattered hills 0.3-1 km across' were interpreted as Caloris impact ejecta [3]. These plains were subsequently named the Odin Formation, and the knobs associated with them were interpreted as degraded ejecta blocks [4], similar to the Alpes Formation surrounding Imbrium (1250 km diameter), on the Moon [5]. The scale of these knobs makes them amenable to photogeological investigation, which offers an opportunity to learn about the interior of Mercury.

More recent analyses have called into question the ejecta origin for the circum-Caloris knobs. MESSENGER mission data, which have global coverage, have allowed the full extent of the Odin Formation to be mapped [6,7]. Impact crater counts reported in multiple studies [6,7,8] find that the Odin Formation has a crater size-frequency distribution indicating that it is distinctly younger than Caloris rim material. This suggests that the Odin Formation has different crater production or retention properties from the Caloris rim material [6], or that the Odin Formation has been resurfaced after its original emplacement as impact ejecta [6,7], or that it is not Caloris impact ejecta at all.

To test for an impact ejecta origin for the circum-Caloris knobs, we have mapped their locations and made morphometric measurements and high-resolution observations. We will make similar measurements and observations of the Montes Alpes on the Moon and compare these data with our results from Mercury.

Methods: We defined a study area from the Caloris rim outwards by 1500 km at all azimuths. In it, we mapped the locations of circum-Caloris knobs using the ~166 m/pixel MESSENGER global monochrome mosaic [9]. The resulting catalogue is complete for knobs with diameter >5 km (n = 285). This improves upon the scope of earlier studies of the circum-Caloris knobs [8,10]. 30 knobs are crossed by high-fidelity Mercury Laser Altimeter (MLA) [11] profiles from which heights and flank slopes can be reliably measured. 29 knobs (including 5 with MLA data) have high-resolution (better than 50 m/pixel) Mercury Dual Imaging System (MDIS) [12] narrow-angle camera (NAC) data, which allowed detailed observations of knob morphology and stratigraphic relationships.

NAC and MLA data have insufficient coverage to characterise the entire population of circum-Caloris knobs. Instead, we have used a modified version of a shadow measurement technique [13] to extract a topographic profile from all knobs with wide-angle camera (WAC) images captured under favourable illumination conditions. This technique can be applied only to knobs that cast shadows onto a flat, adjacent landscape. The cast umbral shadows and umbral terminators of the knobs are digitised using ArcGIS software (Fig. 1). In conventional shadow length calculations, the height, *h*, of an object is given by

$$h = \frac{l_m}{(\tan i \pm \tan e)} \tag{1}$$

where l_m is the maximum shadow length measured in the direction of solar illumination, i is the solar incidence angle, and e is the spacecraft emission angle. A '+' is used when the spacecraft is looking back at the surface towards the Sun, while a '–' is used when the

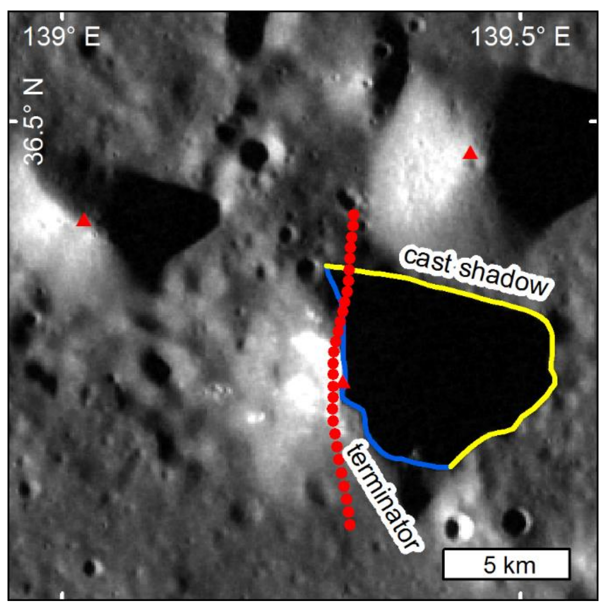

Fig. 1. *Three circum-Caloris knobs (red triangles). Red dots show shot points for MLA topographic profile in Fig. 3. Yellow and blue lines show digitised knob cast shadow and terminator respectively. This shadow was scaled to produce the shadow profile in Fig. 3.*

Sun is behind the spacecraft [14]. We scaled the digitised shadow in the same manner as [13] in order to produce a profile of continuous height measurements along the terminator of each knob. We have so far digitised the shadows of 68 knobs. We have tested the reliability of this method by comparing its estimations of height and flank slope with those found for the same knob using MLA data (n = 15).

Results: Our map of the circum-Caloris knobs shows that they are not distributed evenly around the basin (Fig. 2). They are more densely distributed near the basin rim but isolated examples occur up to ~1000 km away. They sometimes occur in chains that radiate away from the centre of Caloris, some of which are coincident with secondary impact crater chains. This is strong evidence that they are Caloris impact ejecta blocks and suggests that the unexpectedly low crater size-frequency distribution of the Odin Formation may be due to unusual crater production or retention properties.

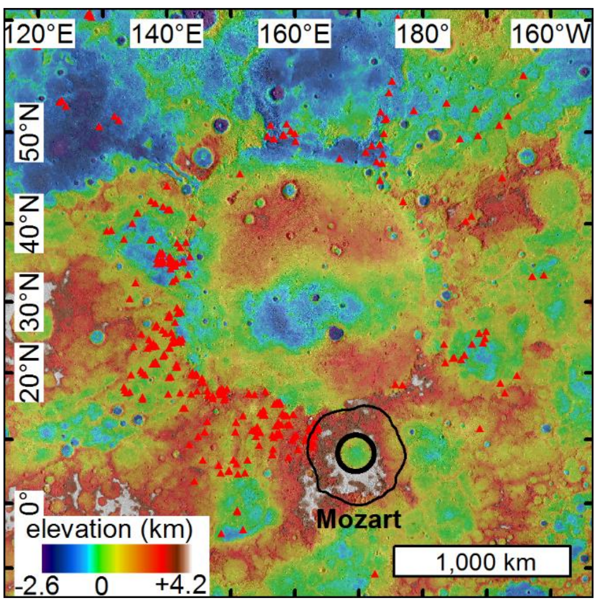

Fig. 2. *Topography of the Caloris basin. Locations of circum-Caloris knobs >5 km (red triangles). Mozart rim and ejecta (black lines). Mercator projection.*

The regions around Caloris with low knob spatial density are commonly occupied by smooth plains [7], consistent with the hypothesis that knobs were originally distributed around the entirety of the basin, but have since been buried by post-impact volcanism, with only the knobs on high topography (e.g. pre-Caloris crater rims) escaping burial. The region of low knob spatial density close to the SSE portion of Caloris' rim is coincident with the Mozart impact basin and its ejecta (Fig. 2). We have made no observation that suggests the asymmetric distribution of circum-Caloris knobs is a primary effect of an oblique Caloris impact.

From initial comparisons, we find that the shadow technique produces useful estimations of knob height and upper flank slope (Fig. 3). The technique is less effective at reproducing lower flank slopes. This effect is probably due to the Sun acting as an extended light source on Mercury, so that penumbral shadow causes the technique to break down when used on low-angle slopes.

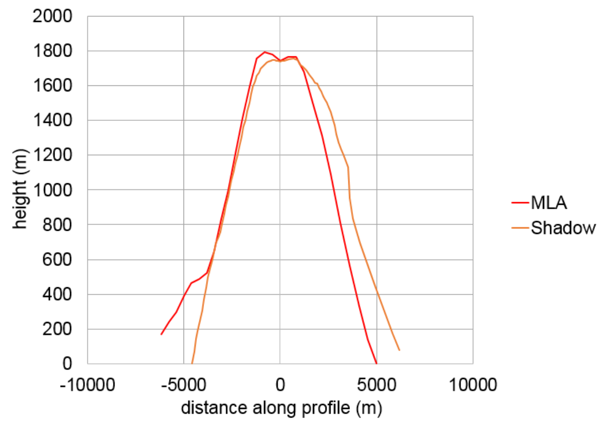

Fig. 3. *An example of a comparison between knob topography from MLA and shadow data. See Fig. 1.*

Future Work: We will continue to use the shadow measurement technique of [13] to measure the heights and flank slopes of all suitable circum-Caloris knobs. We will make similar measurements of the knobs within the Alpes Formation on the Moon. We consider this to be an important comparison to make since Caloris and Imbrium are of similar size and age, and since Mercury and the Moon have similar geological histories but different apparent interior compositions, perhaps explaining any differences that emerge in the geomorphology of these ejecta blocks.

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